Impacts of energy price changes on the financial viability of agricultural groundwater wells in Tulkarm district, Palestine

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Abstract: Water scarcity has often been recognised as a major challenge to sustainable development and viability of the anticipated Palestinian State. Recently, after the evolution of increasing oil prices, energy has become another major challenge. Groundwater, which is the major source for Palestinians, depends greatly on diesel and electricity whose prices have increased drastically during the past years. This paper studies the potential impacts of diesel and electricity price changes on the financial viability of groundwater extraction from agricultural wells. The study is based on a field survey that targeted 33 agricultural groundwater wells in Tulkarm district. The results show that the financial profit from electricity-driven wells is much higher than that of diesel-driven wells. The financial profit from diesel-driven wells is highly elastic to diesel price changes. On the contrary, the financial profit from electricity-driven wells is inelastic to electricity price changes.

Keywords: diesel prices; electricity prices; extraction costs; financial profit; Middle East.

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1 Introduction

Ensuring sufficient water is one of the most fundamental challenges to sustainable development, economic growth and political stability in the Middle East and North Africa (MENA) region, in general, and in the Occupied Palestinian Territories (OPT), in particular. Water security is especially critical to viability of the anticipated Palestinian State where the long-term challenge for water resource managers is to sustainably increase water supply while managing the water demand. The political conflict between Palestinians and Israelis exacerbates the challenge, as Palestinians do not have full control over their water resources that are shared with the Israelis. Therefore, the main water resources for the Palestinians in the West Bank and Gaza Strip and Israelis include groundwater from two main aquifers (mountain and coastal) and various springs, as well as surface water from the tributaries of the Jordan River and Lake Tiberias (Figure 1). The mountain aquifer is divided into three aquifer basins: western, north-eastern and eastern. The West Bank obtains most of its water from the mountain aquifer, some from Israel and some from springs. Gaza's supply comes predominantly from the coastal aquifer (Weinthal et al., 2005). The Palestinians were denied from access to the Jordan River water since occupation in 1967. According to Article 40 of Oslo II Accord signed between Palestinians and Israelis in 1995, the groundwater quantities available for exploitation from the three mountain aquifer basins are estimated at 600–660 MCM/year. However, the Palestinian consumption from these basins is limited to 115–123 MCM/year; the remaining parts are exploited by the Israelis (Abu Zahra, 2001; Daibes, 2002; RAND, 2007). The Gaza Strip consumption from the coastal aquifer is estimated at 110 MCM/year (RAND, 2007). In addition, the agreement enables the Palestinians to develop additional 24 MCM/year of unexploited resources in the West Bank and 5 MCM/year in the Gaza Strip. Furthermore, the agreement estimated that the future needs of the Palestinians might rise to 70–80 MCM/year (Oslo II Agreement, Article 40, 1995). The remaining water issues were reserved to final status negotiations that never occurred, and not all of the agreed-upon quantity has been released, especially after interruptions in the negotiations owing to the second Intifada (uprising) that began in September 2000. Because these issues have not been resolved, Israel continues to consume water according to historical use, and the West Bank and Gaza Strip are unable to support their increasing needs. Moreover, the construction of the 'Separation Wall' exacerbated the complexity of the conflict over the water resources, as many groundwater wells became on the Israeli side of the wall.

Groundwater is pumped from shallow and deep aquifers through agricultural and domestic wells that were constructed during the Jordanian mandate before 1967. The Israelis impose restrictions on construction of new additional wells by Palestinians, and limit the annual pumping rates from each of the existing wells to specific quotas. Most of the wells are owned by individual farmers or farmers' cooperatives and meant for agricultural irrigation. The owners of the wells use part of the produced water for irrigation of their own lands and sell excess water to neighbouring farmers. Nowadays, supplying drinking water to towns and villages from the agricultural wells is a growing business because it is more profitable to the owners of the wells than selling irrigation water.

Most importantly, the global crude oil market reflects on the prices of electricity and diesel that play a significant role in the Palestinian economy,[1] in general, and in the water sector, in particular. The existing wells in the OPT are driven by diesel or electrical pumps. Rapidly growing oil demand coupled with dwindling supplies was expected to dramatically increase the global crude oil prices that exceeded 135 US$/bbl in July 2008[2] (APPGOPO et al., 2008; Rhodes, 2009). However, against all expectations, the global oil prices have decreased substantially in response to the global financial crisis – that have evolved in the USA in September 2008 – reaching about 40 US$/bbl in December 2008 (APPGOPO et al., 2008; EIA, 2009; Rhodes, 2009). In response to global crude oil prices, the diesel and electricity prices in the West Bank have risen substantially during the past few years (Table 1 and Figure 2). Since 2000 until July 2008, diesel and electricity prices in the West Bank have increased by 283% and 46%, respectively. In response to reductions in global crude oil prices, the diesel prices in the West Bank have been reduced to 1.25 US$/litre in December 2008, whereas the electricity prices have not changed. However, since 2000 until now, the domestic and irrigation water tariffs have not changed in pace with fluctuations in the global oil market and local energy charges. This implies negative impact on the financial viability of groundwater production wells. In other words, financial viability of the existing groundwater wells is challenged by increased production costs – through increased diesel and electricity prices – and water demand management initiatives in addition to fixed revenues from the water tariffs paid by farmers and households. The owners of the wells pay for energy prices in the form of diesel purchased from private providers or electricity bills paid directly to the municipality or village council. The diesel prices are set by the General Petroleum Agency of the Palestinian Authority in response to Israeli decisions; the Palestinian petroleum products as well as electricity are supplied originally by Israeli companies through intermediate Palestinian providers. The water tariffs are paid by the farmers directly to the owners/managers of the wells based on one of the two commonly used water measurement systems:

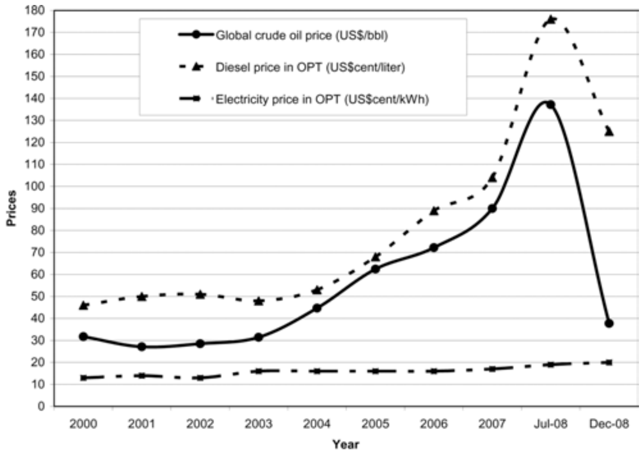
- paying for water pumping hours
- water meter recording.

Figure 1 Location of Tulkarm district

Source: Updated base map of RAND (2007)

The water tariffs are determined through indirect coordination between owners of the wells and local farmers with limited influence from government.

Figure 2 Palestinian energy prices against global crude oil prices



Based on raw data on global crude oil prices (EIA, 2009) and Palestinian energy prices (PCBS, 2008).

Economic literature on groundwater resources emphasises that economically efficient extraction rates of groundwater occur when the net economic benefits are maximised over time (Burt, 1970; Cummings, 1970; Burness and Martin, 1988; Provencher and Burt, 1993; NRC, 1997; Gül et al., 2005). The net economic benefits in this statement cover the societal economic value in addition to the private financial profit from the wells. The economic value of water stems from its scarcity relative to its demand. Whenever water is available in unlimited supply, it is free in the economic sense (Ward and Michelsen, 2002; Ward and Pulido-Velazquez, 2008). In the Middle East, water is the limiting factor (and land is not), thus more private profits might lead to more groundwater pumping and more societal costs, i.e., economically inefficient pumping rates.

Energy prices have a crucial effect on water use efficiency, as water production and irrigated agriculture are heavily dependent on pumps that are powered by diesel or electricity motors. As energy has a high share of the water production and irrigation costs, the diesel/electricity subsidy could have a considerable impact on the farming profitability and on farmers' allocation strategies as well as on intensive groundwater use and aquifer depletion under water scarcity conditions (Gül et al., 2005). The agriculture sector, in general, is often criticised for high wastage and inefficient use of water both at the point of production (i.e., at well level) and at the point of consumption (i.e., at farm level) encouraged by subsidised low energy tariffs for pumping or low charges for water uses (FAO, 2004; Perry, 2001, 2007). In the OPT, energy tariffs for pumping are not subsidised, whereas the water tariffs are low.

Table 1 Average electricity and diesel prices in the West Bank, 2000–2008*

	2000	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*July 2008*	*December 2008*
Electricity tariffs (US$cent/kWh)	13	14	13	16	16	16	16	17	19	20
Diesel tariffs (US$cent/litre)	46	50	51	48	53	68	89	104	176	125
Peak crude oil prices (US$/bbl)	31.7	27.1	28.5	31.4	44.7	62.4	72.2	90	137.2	37.7

*Compiled from different sources, mainly unpublished data of PCBS (2008) and EIA (2009).

The private costs of groundwater extraction are primarily a function of pumping technology (or pump efficiency), the depth from which the groundwater must be pumped and the costs of energy. These costs increase with pumping depth and the cost of energy and decrease as pump efficiency is improved. When groundwater is pumped in an individually competitive manner, pumpers have strong incentives to treat groundwater as an open access resource, with the result that extraction rates exceed the economically efficient rate (NRC, 1997). In general, pumpers have an incentive to extract as much water as possible, depending on the constraints imposed by pumping costs. Incentives to conserve voluntarily are often absent as competitive pumpers often ignore 'user costs'[3] both because they believe that self-discipline will not effectively conserve supplies for the future and because they believe that the impact of their own pumping on the water table will be small (NRC, 1997). When the user costs are ignored, the costs of groundwater extractions are undervalued and water is extracted too quickly. In competitive situations, two types of regulatory measures by groundwater management authorities can be imposed to ensure that pumpers account for the user costs:

- imposition of pumping taxes or reducing/removing subsidies on energy (diesel or electricity)
- imposition of pumping quotas to ensure that the aquifer is not exploited too quickly (Nether, 1990).

In the case of groundwater extraction in the West Bank, pumping quotas are strictly imposed, no pumping taxes are imposed, and no energy subsidies are offered. Nevertheless, the financial viability (private sustainability) of groundwater wells – and the agricultural sector that relies on these wells – is vulnerable to increased pumping costs owing to increasing diesel and electricity charges inline with the global energy prices.

This research paper aims to study the potential impact of diesel and electricity price changes on the financial viability of groundwater extraction from agricultural wells in the Palestinian Territories using Tulkarm district as a case study. We have chosen Tulkarm district as a study area because it is one of the most agricultural areas in the West Bank with large number of groundwater wells.

2 The study area: Tulkarm district

Tulkarm district is one of the eleven main Palestinian districts located in the north-western part of the West Bank (Figure 1). The district lies from 40 m to 500 m above mean sea level. The total population of Tulkarm district is about 175,320 inhabitants distributed over 42 communities (PCBS, 2007a). The district has a moderate climate, which is characterised by rainy winter (October–May) and dry summer (June–September). The yearly average precipitation in the district varies between 530 mm and 630 mm, which is the main source for the western aquifer (PWA, 2005; MOA, 2007).

According to the PCBS (2008), about 183,500 ha of the farm land are cultivated in the OPT of which 90.1% are in the West Bank and 8.9% are in the Gaza Strip. Agriculture depends heavily on rainfall, as less than 5% of the total land area in the WB is irrigated. Fruit trees constitute 66.5% of the cultivated area, whereas vegetables and field crops comprise 8.1% and 25.5% of the cultivated areas, respectively. About 69.3% of the cultivated area in Gaza Strip relies on irrigation, compared with about 7.5% for the West Bank. The area of Tulkarm district covers about 246 km^2, which is 4.35% of the total West Bank area (PCBS, 2008). The cultivated land is about 38.3% of the total area of the district. Rainfed farming constitutes 88.24% of the cultivated area in the district, whereas irrigated farming constitutes 11.6% (PCBS, 2008). Large percentage (53.42%) of the total land is unused or partly used as pastures. The land use patterns in this district are greatly influenced by the topography, climate and the political conflict over land and water resources. Most of the irrigated land cultivates vegetables (e.g., cucumber and tomatoes) under greenhouse agriculture as well as fruit trees (e.g., olives and citrus).

Tulkarm district, as elsewhere in Palestine, suffers from water shortage where the average water consumption for municipal purposes ranges between 50 l/c/d and 70 l/c/d (PWA, 2005; PA, 2007). However, these figures reach 30 l/c/d in some rural communities and 150 l/c/d in Tulkarm city (PWA, 2003). Most communities in the district rely on groundwater wells for domestic water supply. Twelve communities out of 42 in Tulkarm district are still without domestic water supply networks. Agricultural activities in the district consume about 65% of the total water supply (PWA, 2005). Most of the water consumed in the district is pumped from the western aquifer, which is the largest mountain aquifer system in the West Bank. Out of the 287 Palestinian groundwater wells in the West Bank, 63 wells are located in Tulkarm district, 11 wells are restricted for municipal water supply and 52 wells are used mainly for agricultural water supply with a total pumping capacity of about 12.3 MCM/year (PWA, 2005); many of the agricultural wells supply dinking water to neighbouring villages/communities.

The Palestinian Water Authority (PWA) is responsible for strategic planning, monitoring and oversight, policy implementation, regulation and water rights negotiations. Its main goal is to ensure the equitable utilisation and sustainable management and development of Palestinian water resources. The local ministries, utilities and water users' associations are responsible for the actual implementation of the PWA's national water plan. The traditional management systems of agricultural groundwater wells are a major difficulty facing the PWA. These wells are fully managed and operated by the owners, private farmers or cooperatives. Besides this, most of these wells are located in areas outside the control of Palestinian Authority. Therefore, there is discrepancy in water tariff system in the OPT even within each of the districts owing to social, physical, institutional and political sensitivity. The current domestic water tariffs in Tulkarm district range between 0.4 and 1.5 US$/m^3 within block tariff systems (PWA, 2003). The irrigation water tariffs in the district range between 0.25 US$/m^3 and 0.37 US$/m^3, which are based on the operation and maintenance costs of groundwater pumping (MOA, 2006). These irrigation water tariffs are high as reflected by high marginal cost and relatively low marginal productivity in term of US$/m^3. According to Shatanawi (2006), the financial return of major crops in OPT is 0.08, 0.33, 0.37 and 2.03 US$/m^3 for citrus, vegetables, fruit trees and protected agriculture, respectively. According to PWA (2003), the share of energy cost to the total operation and maintenance costs of water production from groundwater wells varies from 2.8% in Bethlehem to 25.0% in Tulkarm, up to 61.7% in Nablus. This discrepancy is attributed to

- diversity of energy sources used in extracting
- wells' depth
- efficiency of the means of water production and pumping
- lack of a central authority entrusted with supervising and monitoring the sector and setting water prices (PWA, 2003)
- political and social influences.

3 Approach and methodology

This research study is based on a questionnaire survey that was conducted in Tulkarm district during the last two months of 2006. The questionnaire was prepared in a participatory workshop in close collaboration with all stakeholders that represented water and agricultural experts, farmers, wells owners, municipalities, common public and others. The questionnaire was structured to include different sections and questions on

- the socio-economic characteristics of the wells' owners, such as age, education and gender
- information on the wells' location, age, depth, production rates, working hours, source of energy, etc.
- data on operation and maintenance costs of the wells, such as diesel/electricity expenses and personnel cost.
- data on revenues such as tariffs and quantities for different consumers, water consumption measurement
- information on management of the wells
- perceptions towards increased costs and water tariffs.

The survey team collected data on 41 wells out of 52 agricultural wells in Tulkarm district. The remaining 11 wells were not surveyed because

- some of the owners could not be reached and no alternative persons could take the survey
- few wells' owners refused to take the survey as they suspected using the collected for taxation purposes.

The reliability of collected data was cross-checked by the author in collaboration with experts working in the study area. As a result, 8 wells out of the surveyed 41 wells were eliminated owing to major inconsistencies in the obtained data. However, the exclusion of 19 wells does not have a significant impact on the results, as the sample size (33 wells) represents about 64% of the total number (52) of agricultural wells in the district. The SPSS computer software package and spreadsheet calculations are used for analysis of the collected data.

On the basis of the survey data, the financial profit from wells is calculated as the difference between total annual production costs and total annual revenues (equation (1)). The groundwater production costs are the sum of: diesel or electricity expenses (E), personnel cost (L) and other operational costs (O) that include lubricants, oil filters, pipeline repairs and phone bills, etc. (equation (2)). Calculation of revenues is based on: irrigation water tariffs (T_1), domestic water tariffs (T_2) and water quantities supplied to farms (Q_1) and towns (Q_2) (equation (3)). Changing any of the aforementioned cost or revenue parameters will affect financial profit from the wells according to equation (5).

$$P_o = R - C \tag{1}$$

$$C = E + L + O \tag{2}$$

$$R = T_1 \cdot Q_1 + T_2 \cdot Q_2 \tag{3}$$

$$P_o = T_1 \cdot Q_1 + T_2 \cdot Q_2 - E - L - O \quad (4)$$

$$P_t = (1 + \alpha_{T1})\, T_1\, (1 + \alpha_{Q1}) \cdot Q_1 + (1 + \alpha_{T2})\, T_2 . (1 + \alpha_{Q2}) \cdot Q_2 - (1 + \alpha_E) \cdot E - (1 + \alpha_L) \cdot L - (1 + \alpha_O) \cdot O \quad (5)$$

where

P_o: Current financial profit (US$/year) or (US$/m^3) as in December 2006

P_t: Forecasted financial profit (US$/year) or (US$/m^3)

R: Total revenues (US$/year)

C: Total financial costs of well (US$/year)

E: Energy costs (US$/year)

L: Personnel cost (US$/year)

O: All other operation and maintenance expenses (US$/year)

T_1: Irrigation water tariff (US$/m^3)

T_2: Domestic water tariff (US$/m^3)

Q_1: Quantity supplied to farmers (m^3/year)

Q_2: Quantity supplied to domestic consumers (m^3/year)

α_i: Change ratio of ith parameter (T_1, Q_1, T_2, Q_2, E, L, and O) with respect to its current (December 2006) values (%). For example $\alpha_E = (E_t - E_o)/(E_o)$.

Δ_P: Profit change ratio (%).

The costs of personnel and other production inputs do not change substantially for each well (PCBS, 2007b) although there is significant variability from well to another as our data here demonstrate. Our intention is to highlight the profitability implications of changes in diesel and electricity prices (the energy elasticity of profit), which are the major determinants of groundwater well profitability. As a result, changes in produced water quantities owing to the restrictions imposed on pumping rates and actual historical changes in water tariffs are not explicitly considered. Thus, equation (5) is reduced to equation (6) for forecasting financial profit from wells in response to diesel and electricity price changes.

The financial viability of the wells is represented in terms of profit change ratio (Δ_P), which is the percentage of change in financial profit ($P_t - P_o$) with respect to current profit (P_o) (equation (7)); this is in response to a set of incremental increases and decreases (α_E) to the diesel and electricity expenditures provided by the survey in December 2006. The degree to which a change in energy price will cause a change in profit is called energy elasticity of profit (ε), as represented in equation (8); if ε is greater than 1, profit is considered to have high energy elasticity, and if ε is less than 1, profit is considered to be energy inelastic. The values of energy elasticity of profit (ε) are drawn for each of the surveyed wells.

$$P_t = T_1 \cdot Q_1 + T_2 \cdot Q_2 - (1 + \alpha_E) \cdot E - L - \mathrm{O} \quad (6)$$

$$\Delta_P = (P_t - P_o)/P_o \quad (7)$$

$$\varepsilon = \Delta_P / \alpha_E = \frac{[(P_t - P_o)/(P_o)]}{[(E_t - E_o)/(E_0)]}. \quad (8)$$

4 Results and discussion

4.1 *Financial profit from groundwater wells*

The surveyed wells are characterised by extracting groundwater from the Western basin, which is shared with Israel and by their old construction (35–54 years ago). The depth of wells varies between 60 m and 365 m (avg. 148), depth of the pumps varies between 35 m and 300 m (avg. 98) and their pumping capacity varies between 40 m^3/h and 120 m^3/h (avg. 84) (Table 2). Out of 33 surveyed wells, 27 are diesel-driven and 6 are electricity-driven.

Table 2 Main characteristics of surveyed wells (December 2006)

	N	*Min.*	*Max.*	*Avg.*	*Std. Dev.*
Well age (year)	33	35	54	45.1	4.5
Well depth (m)	33	60	365	147.7	70.4
Pump depth (m)	33	35	300	98.4	48.7
Average pumping rate (m^3/h)	33	40	120	83.8	18.1
Average number of pumping hours per day	33	2	18	8.6	3.9

The results of the study show that diesel and electricity costs represent a large proportion of the total groundwater production costs with an average magnitude of 88.9% (77.6–94.1%) and 82.8% (69.7–88.6%), respectively (Tables 3 and 4). The personnel costs represent 8.3% (4.5–16.8%) and 14.5% (9.0–27.0%) of the total production costs of diesel- and electricity-driven wells, respectively. The other operation and maintenance costs represent 2.7% (1.1–6.2%) and 2.7% (1.9–3.5%) of the total production costs of diesel- and electricity-driven wells, respectively. The average production costs of the diesel- and electricity-driven wells are 0.24 US$/$m^3$ (0.14–0.32) and 0.12 US$/$m^3$ (0.06–0.18), respectively (Table 5). These results reveal that diesel-driven wells have higher recurring costs than electricity-driven ones. The investment costs are difficult to assess because the surveyed wells were constructed long time ago and many of the present owners are comparatively new as they have inherited these wells.

Table 3 Current (December 2006) production costs of the diesel-driven wells (n = 27)

	Energy costs (US$/year)*	*Personnel costs* (US$/year)	*Other O&M costs* (US$/year)	*Total Annual O&M costs* (US$/year)	*Share of energy to total O&M costs* (%)	*Share of personnel costs to total costs* (%)	*Share of other O&M costs to total costs* (%)
Min.	13,000	1000	250	14,250	77.6	4.5	1.1
Max.	121,500	6750	3750	131,750	94.1	16.8	6.2
Avg.	45,250	3796	1269	50,315	88.9	8.3	2.7
Std. Dev.	26,078	1584	904	27,716	4.0	3.0	1.6

Table 4 Current (December 2006) production costs of the electricity-driven wells (n = 6)

	Energy costs (US$/year)*	*Personnel costs* (US$/year)	*Other O&M costs* (US$/year)	*Total Annual O&M costs* (US$/year)	*Share of energy to total O&M costs* (%)	*Share of personnel costs to total costs* (%)	*Share of other O&M costs to total costs* (%)
Min.	15,500	4250	500	22,250	69.7	9.0	1.9
Max.	52,500	7000	1750	59,250	88.6	27.0	3.5
Avg.	35,083	5292	1125	41,500	82.8	14.5	2.7
Std. Dev.	15,364	1077	542	16,165	6.9	6.8	0.7

*All costs and revenues are converted to US$ (1 US$ = 4 NIS, 2006).

Water users of the electricity-driven wells are charged less water tariffs compared with those of diesel-driven wells. The average water tariffs charged to farmers from the diesel and electricity-driven wells are 0.30 US$/m^3 (0.21–0.38) and 0.28 US$/m^3 (0.16–0.35), respectively (Table 5). Accordingly, the average marginal financial profit from diesel- and electricity-driven wells is 0.066 US$/m^3 (0.017–0.124) and 0.196 US$/m^3 (0.171–0.232), respectively. The big variance in range of profit from wells is attributed to:

- different depth of wells
- different number of working hours
- different pumping rates
- different areas of irrigated land
- different quantities and tariffs of water supplied to farmers and non-agricultural users
- different characteristics and conditions of distribution networks
- different management practices.

These results lead to the conclusion that electricity-driven wells are more financially viable than diesel-driven wells as they provide better profit to the wells' owners and low tariffs to the water users. Under conditions of reduced profit from wells, the owners will have to apply some of the following adaptation measures as alternatives to closing business:

- reducing extraction rates
- reallocating their water supplies from agricultural to domestic users
- increasing water tariffs.

Therefore, the government should monitor the groundwater extraction to ensure that wells' owners sustain some financial profit without reducing agricultural and domestic water supplies.

Table 5 Financial profit from the wells at current production costs (December 2006)

	Annual pumping rate (m^3/year)	*O&M costs* (US$/$m^3$)	*Tariffs to farmers* (US$/$m^3$)	*Total annual O&M costs* (US$/year)	*Gross annual revenues* (US$/year)	*Annual financial profit* (US$/year)	*Unit financial profit* (US$/$m^3$)
Diesel-driven wells (n = 27)							
Min.	55,845	0.135	0.205	14,250	18,889	2210	0.017
Max.	473,040	0.320	0.375	131,750	177,390	45,640	0.124
Avg.	215,168	0.238	0.296	50,315	66,263	15,948	0.066
Std. Dev.	111,815	0.052	0.051	27,716	38,346	13,752	0.033
Electricity-driven wells (n = 6)							
Min.	275,940	0.055	0.156	22,250	85,410	49,254	0.171
Max.	473,040	0.181	0.353	59,250	137,970	97,650	0.232
Avg.	371,753	0.117	0.281	41,500	114,887	73,387	0.196
Std. Dev.	71,623	0.054	0.079	16,165	19,671	18,794	0.021

The study could not find strong correlations between profit from wells and other input/output variables such as well depth and age and operators' education. The poor correlation between profit and well depth is attributed to the hydraulic differences of distribution networks associated with each well and thus specific energy requirement. Energy requirement is determined by pumping rate, working pressure head and efficiency of motor and pump (kwh = $\rho g \mathrm{QH}/\eta_m \eta_p$). These three parameters vary substantially from one well to another depending on the length of distribution network and elevations, age and efficiency of pumps and motors, wells' depth and availability of balancing storage reservoirs.

4.2 *Impact of changing energy costs on profit from groundwater wells*

The study reveals that energy prices have substantial impact on the groundwater production costs and thus have severe effect on financial profit from the wells. However, the level of impact on the diesel-driven wells is more than that on the electricity-driven ones. The results show that increasing the current diesel and electricity prices by 10%, will drop the marginal profit from diesel- and electricity-driven wells to 0.045 US$/$m^3$(−0.13 to 0.108) and 0.186 US$/$m^3$ (0.158–0.225), respectively (Table 6); in terms of profit change ratio (Δ_P), this means −44.7% (−173.3 to −13.4%) and −5.2% (−8.9 to −2.3%), respectively (Table 7). In this case, all wells but one (diesel-driven) can withstand increasing the diesel and electricity prices by 10%. On the other hand, decreasing the current diesel and electricity prices by 10% will increase the marginal profit from the diesel- and electricity-driven wells to 0.087 US$/$m^3$ (0.047–0.142) and 0.206 US$/$m^3$ (0.185–0.239), respectively; in terms of profit change ratio (Δ_P), this means 44.7% (13.4–173.3%) and 5.2% (2.3–8.9%) for diesel- and electricity-driven wells, respectively. Similarly, the number of diesel-driven wells that cannot withstand the increasing diesel prices by 20, 50 and 100% are 17, 20 and 27 (all), respectively.

Table 6 Forecasted financial profit from the wells at incremental diesel and electricity price changes (December 2006)

	P_t = *Forecasted profit* (US$/m^3)					
	$\alpha_E = -50\%$	$\alpha_E = -10\%$	$\alpha_E = 10\%$	$\alpha_E = 20\%$	$\alpha_E = 50\%$	$\alpha_E = 100\%$
Diesel-driven wells (n = 27)						
Min.	0.110	0.047	–0.013	–0.042	–0.131	–0.279
Max.	0.229	0.142	0.108	0.091	0.041	–0.038
Avg.	0.172	0.087	0.045	0.024	–0.040	–0.146
Std. Dev.	0.034	0.031	0.034	0.037	0.047	0.067
Number of wells that would withstand increased costs; i.e., $P_t > 0$	27	27	26	17	7	0
Number of wells that would not withstand increased costs; i.e., $P_t < 0$	0	0	1	10	20	27
Electricity-driven wells (n = 6)						
Min.	0.214	0.185	0.158	0.144	0.099	0.020
Max.	0.269	0.239	0.225	0.219	0.198	0.164
Avg.	0.245	0.206	0.186	0.176	0.147	0.097
Std. Dev.	0.023	0.019	0.025	0.028	0.041	0.064
Number of wells that would withstand increased costs; i.e., $P_t > 0$	6	6	6	6	6	6
Number of wells that would not withstand increased costs; i.e., $P_t < 0$	0	0	0	0	0	0

Table 7 Profit change ratio of the wells at incremental diesel and electricity price changes (December 2006)

	Δ_P = *Profit change ratio* (%) = $(P_t - P_o)/P_o$					
	$\alpha_E = -50\%$	$\alpha_E = -10\%$	$\alpha_E = 10\%$	$\alpha_E = 20\%$	$\alpha_E = 50\%$	$\alpha_E = 100\%$
Diesel-driven wells (n = 27)						
Min.	67.0	13.4	–173.3	–346.5	–866.3	–1732.7
Max.	866.3	173.3	–13.4	–26.8	–67.0	–133.9
Avg.	223.4	44.7	–44.7	–89.4	–223.4	–446.9
Std. Dev.	173.8	34.8	34.8	69.5	173.8	347.7
Electricity-driven wells (n = 6)						
Min.	11.7	2.3	–8.9	–17.8	–44.4	–88.8
Max.	44.4	8.9	–2.3	–4.7	–11.7	–23.4
Avg.	26.1	5.2	–5.2	–10.4	–26.1	–52.2
Std. Dev.	14.9	3.0	3.0	6.0	14.9	29.8

The sensitivity of profit change ratio (Δ_P) to diesel and electricity price changes (α_E) is expressed in terms of elasticity of profit (ε) for each of the surveyed wells (Figures 3 and 4). The average elasticity of profit (ε) is −4.47 (−17.33 to −1.34), which is more than 1 for all diesel-driven wells (Table 8); thus, highly elastic relationship between profit and diesel price changes. In conclusion, profit from diesel-driven wells is extremely sensitive to even low levels of diesel price changes. The case of electricity-driven wells differs substantially as the electricity prices have not changed. Therefore, all the surveyed electricity-driven wells can withstand even doubling of the current electricity prices (Table 6). The elasticity of profit (ε) is −0.52 (−0.89 to −0.23), which is less than 1 for all electricity-driven wells (Table 8); thus, inelastic relationship between profit and electricity price changes. In conclusion, profit from electricity-driven wells has low sensitivity to electricity price changes.

Figure 3 Energy elasticity of profit ($\varepsilon = \Delta P/\alpha_E$) of all surveyed diesel-driven wells (n = 27) (see online version for colours)

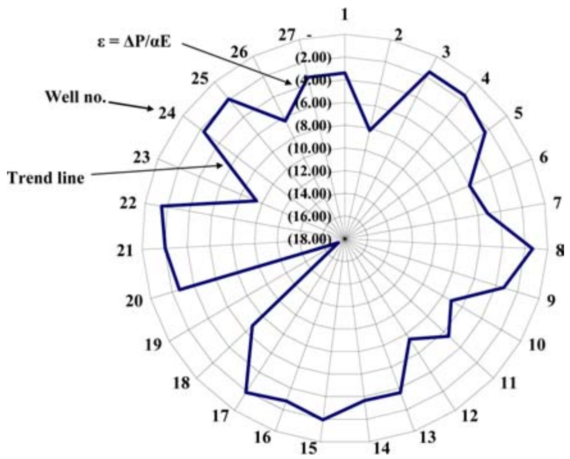


Figure 4 Energy elasticity of profit ($\varepsilon = \Delta P/\alpha_E$) of all surveyed electricity-driven wells (n = 6) (see online version for colours)

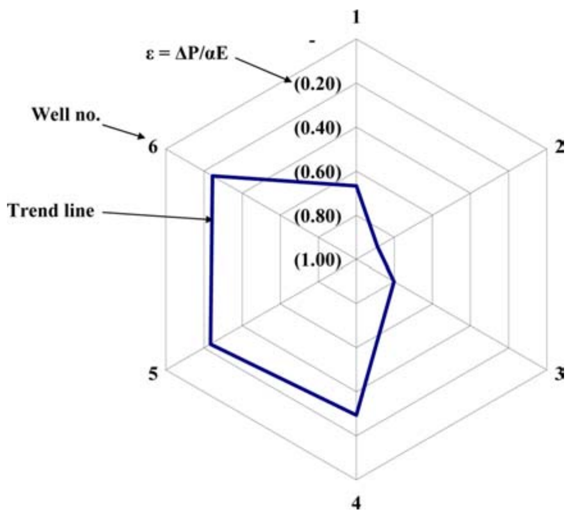


Table 8 Energy elasticity of profit of diesel and electricity driven wells

	$\varepsilon = \Delta_P/\alpha_E$	
	Diesel-driven wells (*n* = *27*)	*Electricity-driven wells* (*n* = *6*)
Min.	−17.327	−0.888
Max.	−1.339	−0.234
Avg.	−4.469	−0.522
Std. Dev.	3.477	0.298

Replacing a diesel motor with an electric one could be very expensive, which many well owners cannot afford. This depends on the availability of electricity network and appropriate transformer and proximity to the well. Many of the wells are located in remote agricultural areas that are not served with electricity. Therefore, government, aid agencies and NGOs that are concerned about improving the agricultural sector and farmers' livelihood are recommended to improve electricity infrastructure in the neighbourhoods of groundwater wells. Moreover, more effort is needed on raising awareness of groundwater extractors on the benefits of converting diesel-driven wells into electricity-driven ones.

It is worth mentioning that at the time of peak diesel prices in July 2008, the irrigation water tariffs were increased to about 0.38 US$/m^3. Meanwhile, in partial response to recent decreases in global oil prices, the diesel prices in the West Bank have decreased from 1.76 US$/litre in July 2008 to 1.25 US$/litre in December 2008 (Table 1 and Figure 2); since then, the electricity and water tariffs have not changed accordingly.

5 Conclusions

Under the prevailing conditions of water shortage, political conflict and economic hardship, groundwater wells remain the major source of water for Palestinian farmers and localities. Energy expenses that dominate the costs of groundwater production have increased substantially following the global crude oil market in the past few years. Energy expenses have substantial impact on the financial profit from wells, and thus influence local decisions regarding the magnitude of groundwater extraction and its allocation between agricultural and domestic consumers. On the one hand, increased energy prices reduce profit from wells and might decrease the amounts of water available for agricultural and domestic uses. Therefore, the groundwater extractors are tempted to allocate their water to the domestic consumers instead of agricultural irrigation owing to water tariffs discrepancy between the two sectors. This has severe negative impacts on water availability for the agricultural sector and threatens its sustainability. On the other hand, decreased energy prices increase profit from wells and might encourage over pumping of groundwater. In reality, however, the wells have restricted extraction quotas. This calls for the effective monitoring of groundwater extraction to ensure that viability of wells and agriculture do not compromise the sustainability of the groundwater aquifers.

The study shows that in response to energy price changes, the financial viability of diesel-driven wells is more sensitive than that of electricity-driven ones. In other words, the diesel-driven wells are highly elastic to diesel price changes.

The electricity-driven wells are inelastic to electricity price changes. The Palestinian governmental and non-governmental organisations are recommended to assist the wells' owners in converting diesel-driven wells into electricity-driven ones. This implies improving the electricity infrastructure in the neighbourhood of groundwater wells and raising extractors' awareness on the benefits of converting the diesel-driven wells into electricity-driven ones.

Further research is needed on the implications of groundwater extraction from agricultural and domestic wells on the social, economic and environmental sustainability of the groundwater aquifers.

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Notes

[1]Increased energy prices have a negative influence on economic growth, as increasing the production cost of commodities leads to increased prices, thus entails reduced demand.

[2]This research survey was conducted during the last two months of 2006, at the time that global oil prices were close to the peak values.

[3]The term 'user costs' applies to a wide range of effects of groundwater use beyond the costs of production. User costs are defined as costs incurred by groundwater water users and the community at-large as a result of groundwater depletion.